Chain Printer and ending with the 3262 (a band printer with special characteristics for improved "ease of use"). In serial matrix printing, emphasis is given to the wire-matrix print head, with examples of both the "no-work" magnet (as embodied, *e.g.*, in the IBM 2213) and the "work" magnet (used first in the 3767 and subsequently in the 3287). In addition to these major technologies, the authors also review certain special applications and assess, where appropriate, what has been learned about print quality, techniques for integration of printing with other system functions, human factors and ease of use, and reliability.

In the final paper in this section, Elzinga *et al.* describe the development of IBM's electrophotographic and laser-imaging technologies. Essentially, the engineering task was to extend the copier-based electrophotographic reproduction process and combine it with high-speed laser image generation to meet new needs for system printing. In achieving that basic objective, a number of problems had to be solved: The imaging technology required a long-life, stable laser system; electrophotographic process speeds had to be increased to levels consistent with high-speed printing; paper-handling systems had to accommodate both continuous-form and cut-sheet applications with equal reliability; and the entire process had to be controlled so as to be compatible with asynchronous computer-to-printer operation. To illustrate how these problems were solved and the new technologies are used, the authors describe two specific machines—the IBM 3800, a high-speed system printer announced in 1975, and the IBM 6670 Information Distributor, a combination copier and printer with communications capability that was announced in 1979.

Since magnetic media cannot, in general, be "read" by the human senses, and display output, while readable, is ephemeral (aside from clumsy recourse to photography), printing in some form will remain an essential part of the information resource for the foreseeable future. We hope that reading these papers will lend some insight into this complex and sometimes little-recognized field.

Editor

H. S. Beattie
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IBM Typewriter Innovation

The evolution of the writing machine from early eighteenth-century concepts to the modern electronic typewriter represents a rich history of innovative efforts by many individuals in several countries. This paper briefly highlights several significant early milestones and then draws particular attention to typewriter developments within the IBM Corporation. After entering the typewriter business in 1933, IBM expanded the applicability of electric typebar machines and introduced proportional spacing to electric typewriters. The IBM SELECTRIC® Typewriter single-print-element concept represented a major departure from traditional typewriter design. Since the introduction of the SELECTRIC Typewriter, it has evolved in several directions that resulted in the following: a typewriter to produce high-quality printing for cold-type composing applications; an input/output writer for use in terminals, computer consoles, and word processing machines; a typewriter that can correct errors by mechanically removing them from the page or covering them up; and electronic typewriters, using microcircuitry, that provide more memory and computing power than some early computers.

Early innovation

The idea of the typewriter can be traced to the early eighteenth century. On January 7, 1714, Queen Anne of England granted the first known patent for a typewriting device to Henry Mill, an English engineer [1, 2]. Mill's invention was described as "an artificial machine for the impressing or transcribing of letters singly or progressively one after another as in writing" [2]. It wasn't, however, until 1867 that the device that led to the first U.S. commercial typewriter was patented by Christopher Latham Sholes, a Milwaukee printer.

Much work preceded the Sholes typewriter. In 1829 President Andrew Jackson signed U.S. Patent 259, the first writing machine built in the United States [1, 2]. Invented by William A. Burt of Detroit, it is also considered to be the first typewriter capable of practical work. It lacked a keyboard, however, and an operator caused type to be moved to the printing point by turning a wheel [1]. Four years later, the first machine to utilize individual typebars which converged at a common printing point was conceived and built by a Frenchman, Xavier Progin [1, 2].

The period that followed saw many inventive efforts of varying significance; however, throughout this period of early development the commercial possibilities of the typewriter seemed to elude inventor after inventor. Many, in fact, were motivated to find a way to assist the blind or handicapped [1].

As mentioned, the first U.S. commercial typewriter evolved from the unit invented and built by Christopher Sholes in 1867. Introduced to the market by Remington in 1874 as the "Type Writer," the unit proved to be neither very reliable nor commercially successful and was soon to be replaced by the Model 2 [1, 2]. This early typewriter had its limitations—it typed nonvisibly (the operator could not view the result while typing) and printed only in capital letters. Through many innovations, this limited mechanical device was to evolve into today's sophisticated electronic typewriter.

• *Shift-key mechanism*

The first of these improvements was the shift-key mechanism. To avoid increasing the number of keys to print

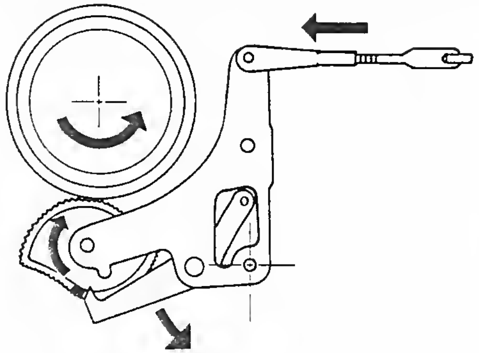

Figure 1 Power roll assembly.

both capital and lower-case letters, two type faces were placed on each typebar. When a letter key was operated in combination with a platen-shifting mechanism, either the capital or lower-case version of the letter could be chosen to print. This device reached the market in 1878 [3].

• *Visible writing*
Another innovation was visible writing. Interestingly, the visible writing line design was staunchly opposed by the manufacturers of the "nonvisible" machines who rationalized that it was a disadvantage to see what one currently was typing. Actually, Progin's machine (1833) was the first to provide visible writing; however, the operator had to look down through the machine to see the typed copy. The Italian inventor, Giuseppe Ravizza, quite taken with the concept of visible writing, began his experiments in 1860. He claimed inventing a "visible" machine in 1872, but did not file a patent until 1883. It wasn't until after 1895, however, that a machine appeared that truly resembled the instrument we know today. Meanwhile, the battle of the "visibles" *versus* "nonvisibles" raged on until 1908, by which time most manufacturers had gone "visible" [2].

• *Electrification*
Electrification was a very significant advance. Although earlier efforts have been recorded (*e.g.*, the Blickensderfer electric, *circa* 1902), the modern powered typebar typewriter traces its roots to the inventiveness of James Fields Smathers [1]. Taking inspiration from the rollover cam action of a hayraking machine, Smathers devised a rollover cam driven by a rubber power roll to impart power to the typebar action (Fig. 1). Evolving from the initial concept of a belt-operated bank of typewriters driven by a common motor, the electric typewriter soon employed a small motor and mechanically operated clutching device to power various functions of the machine. These machines were slow in developing and had little effect on the market until the mid-1930s when IBM entered the picture.

IBM typebar innovation
IBM saw the potential of the electric typewriter and purchased the Electromatic Typewriter Company of Rochester, New York, in 1933. Electromatic had thirty employees in its plant, a total of six salesmen, and some valuable patents. In 1934, IBM invested more than a million dollars to improve the basic Electromatic design, diversify the product line, and modernize the manufacturing facilities.

Electromatic Typewriters did not find rapid and complete acceptance in the marketplace. People had to be convinced that the electric typewriter was safe, reliable and efficient.

• *Early special application devices*
In addition to redesigning the acquired Electromatic, IBM directed innovative engineering effort toward special applications that would emphasize the benefits offered by electric typing, including the ability to make more carbon copies, cut a better stencil, and make a clearer ditto master. This effort yielded a rapidly expanding product line, including among others an Automatic Formswriter, a Toll Biller, and the Hektowriter, a device to prepare masters for a then-popular process called liquid hectograph duplicating.

The Automatic Formswriter provided means to eliminate some of the manual operations required to advance and detach multipart forms while inserting and removing interleaved sheets of carbon paper. The Toll Biller was specially designed to prepare telephone bills. Equipped with a paper chute for quick insertion of bill forms, the Toll Biller also incorporated a number of novel features including multiple print cycles from a single keystroke and an automatic carriage return to increase operator efficiency. The Hektowriter introduced the concept of using a carbon ribbon with three printing positions to prepare masters for the liquid hectograph duplicating process. Previously, sheet carbon paper had been used at considerably higher cost and inconvenience. The Hektowriter was an important factor in bringing liquid duplicating machines into general use.

• *Proportional spacing*
Proportional spacing, as developed by IBM, was the last major advance in electric typebar typewriters. Interestingly, the proportional (or variable or differential) spacing concept was not new when IBM introduced its product in 1941. Over one hundred years previously, Progin in his 1833 model allotted different spaces for upper-case and lower-case letters [2]. A number of other inventors employed the principle and several manufacturers produced machines in the 1880s, including the Maskelyne (1889) [2, 3]. Probably due to mechanism complexity and cost, differential spacing was abandoned around the turn of the century [2]. Many years later, new impetus for a typewriter that would more closely reproduce the product of the professional printer came from Electromatic customers who desired higher-quality printing at typewriter costs.

Ever since the invention of movable type, each letter in the alphabet had been given a unique width to make its appearance pleasing to the eye. The conventional fixed-escapement typewriter required that all characters be of equal width. This squeezed large characters such as M and W and provided more than ample space for the thinner characters such as i and l. To provide variable spacing for different letters, IBM's first proportional spacing typewriter used a rotary type of escapement mechanism of three separate escapement wheels designed to provide 2, 3, or 4 units of carriage motion [Fig. 2(a)]. Used in combinations, it was possible to obtain 2, 3, 4, 5, or 6 units of carriage travel, which provided a wide range of possible character widths and a more pleasing quality of print. A subsequent design employing a multiple-pawl linear escapement [Fig. 2(b)] was first used in the Model A Executive and has remained basically unchanged for more than thirty years.

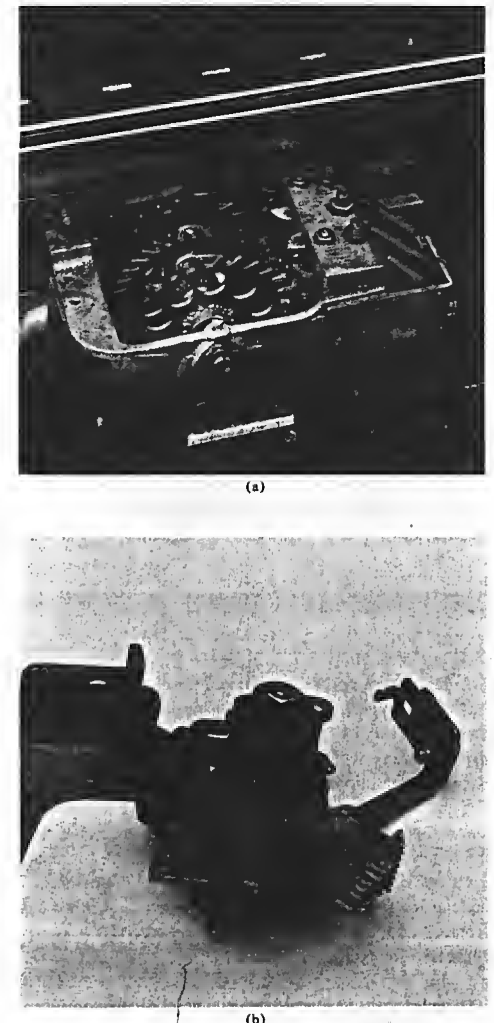

Figure 2 (a) Rotary escapement mechanism for proportional spacing; (b) linear escapement mechanism of the Executive electric typewriter.

IBM SELECTRIC® Typewriter
The IBM SELECTRIC Typewriter represented a radical change from the highly refined mechanical system of the typebar typewriter. It was not, however, the first typewriter to use a single print element. Several early machines placed all type characters on a single part. One that was built by an American, John Pratt, in 1866 had the type engraved on a half-inch-diameter cylinder that could be raised and rotated to select the character to be printed. A number of similar machines were manufactured during the nineteenth century, including the Crandall (1879), Hammond (1886), Chicago (1890), and Blickensderfer (1893) [1, 2, 4].

The IBM SELECTRIC Typewriter, rooted in the development in 1946 of an experimental single-element high-speed printer for accounting machines (Fig. 3), was perceived as a means to eliminate the problem of clashing typebars experienced in conventional typewriters. Following the success of designing and using single-element printers for data processing at speeds up to 2000 characters per minute (eventually 3000 characters per minute in the IBM 370 Printer), the basic SELECTRIC Typewriter configuration emerged in the early 1950s: a spherical single printing element mounted on a moving carrier and a fixed paper carriage (Fig. 4). These characteristics offered key advantages as well as posing some different engineering problems [5].

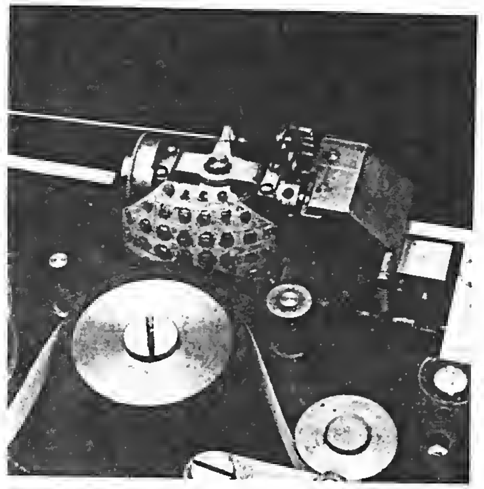

Figure 3 "Mushroom" print element mounted on double gimbal.

Figure 4 Typehead-carrier-paper relationship.

• *Single element*

Since all characters were engraved on a single part, the SELECTRIC Typewriter offered the opportunity to interchange type styles. The interchangeable elements could provide a variety of type styles within a single document as well as the opportunity to use foreign language fonts. The shape of the type element (Fig. 5) was chosen as a sphere because of its space efficiency and because the line of print force is always directed through the tilt axis. Each individual type face was selected by choosing an angle around two mutually perpendicular axes known as "rotate" and "tilt." There were twenty-two positions of rotate and four positions of tilt [5].

To cause the type element to rotate and tilt appropriately to obtain the desired character, a selection system was required. The initial design choice was a system of cams, pulleys, and metal ribbons; however, this lacked the rigidity necessary for the cycle rate desired. This gave way to the "whiffletree" (Fig. 6), a differential arrangement of pivoted bars similar to the bar with the same name to which the traces of a (horse-drawn) wagon harness are fastened. The "whiffletree" provided fixed units of displacement which could be added or subtracted to obtain the desired rotate and tilt motion.

Since the characters were arranged on the print element in two hemispheres (upper-case and lower-case) of 44 characters each and each hemisphere was arranged in 4 rows of 11 characters each, a coding scheme had to be devised to access each character on the element. From a home position in each hemisphere, rotation of up to five positions in either direction and tilt of up to three positions was required. Tilt values of 1 and 2 in all combinations provided access to the four rows of characters. Rotate values of 1, 2, and 2 in selected combinations provided positive rotation from one to five positions from home. A fourth rotate value of −5, in combination with the three positive values, yielded negative rotation from one to five positions from home. Thus, in addition to an eleven-unit motion for upper-case shift, six decisions were required for each character selection.

The keyboard triggered the appropriate decisions when a key was depressed (Fig. 7), setting up its corresponding coded interposer. This interposer, in turn, was driven by a rotating "filter" shaft and engaged a predetermined set of selector bails. These bails engaged the latch interposers, which in turn pulled the selector latches of the "whiffletree" to cause appropriate rotate and tilt motion. Since power to pull the bails and latches was supplied by the rotating filter shaft and not the operator, the designers were free to optimize the keyboard "touch." Encoding the keystroke in this manner not only made the machine simpler, it also made it readily adaptable as an input/output typewriter.

• *Moving carrier*

With few exceptions, in previous typewriter designs the printing apparatus (most often a typebar basket) was held stationary and the paper carriage moved. One notable exception was the electric type-wheel machine patented by Thomas A. Edison in 1872. Also, in Book Typewriters offered by several manufacturers in the 1890s, the entire machine—keyboard and typebars—moved on rails above the horizontal page [2]. In the SELECTRIC Typewriter, it was decided to move the printing element and hold the paper carriage stationary to provide several advantages: a lower parts count, less tendency of the machine to "walk" during typing and carrier return, an opportunity to enclose the typing area to reduce acoustic noise, more reliable continuous-forms feeding, and the opportunity to add automatic paper and ledger feeds.

• *Fixed-cycle operation*

The SELECTRIC Typewriter, in contrast to typebar typewriters, was designed to operate with a fixed machine cycle. This made possible a more reliable and smoother operating machine because the timing of events was not in the hands of the operator but under control of a camshaft that ran one cycle for each character printed. While this design provided a predictable print cycle time, it wasn't a complete answer. Because typists have a tendency toward irregular typing rhythms, the SELECTRIC needed a means to smooth out speed bursts. Without this, the SELECTRIC Typewriter would experience misselection, character drop-out, or even machine damage. This problem was solved by designing keylever interlocks. When a keylever was depressed, all others were inhibited until after the start of the decision-making cycle. Then, a second keylever could be depressed and held in storage until the first print cycle was complete. Thus most operator speed bursts could be accommodated and proper operation ensured.

Since the SELECTRIC Typewriter was a radical change from the typebar typewriter, numerous changes in manufacturing approach were required to put the machine into production. For instance, completely different fabrication techniques were needed for new materials (such as powdered metal and molded plastics) that had not previously been used in manufacturing IBM typewriters. Overall, assembly required handling many more small, intricate parts and new production techniques had to be learned. Dependable adjustments could no longer be made by eye. Eight gauges, for example, were used to connect the selection system to the carrier and rocker assembly. Based on pilot manufacturing experience, many changes were also made in the machine's design. In fact, manufacturing efforts to ensure manufacturability and increase product reliability resulted in a significant reduction in the

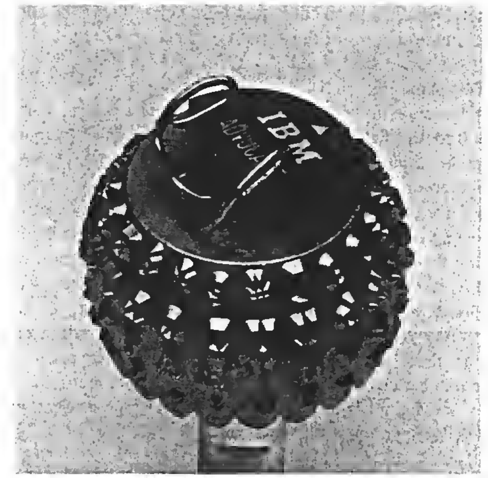

Figure 5 Print element of the SELECTRIC Typewriter.

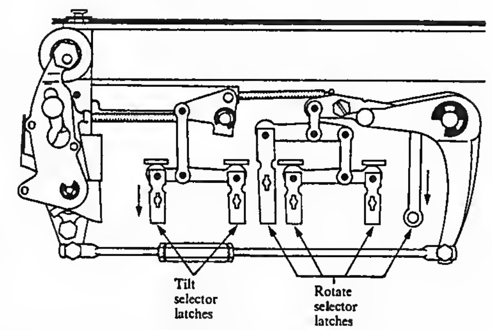

Figure 6 Tilt-and-rotate selector system.

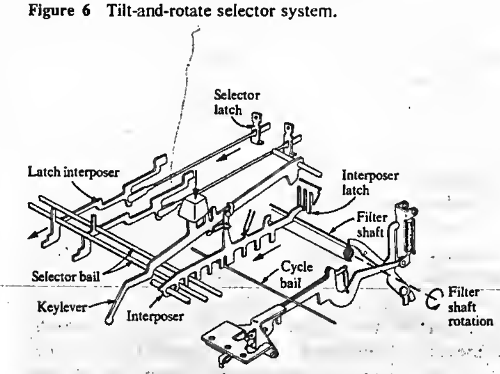

Figure 7 Keyboard and character selection mechanism.

total machine parts count and were key to the initial and ultimate success of the SELECTRIC Typewriter.

Supplies
Innovation in typewriter development has not been limited to the field of electromechanics. Supplies (carbon paper, ribbons, etc.) have played a progressively more important role in moving typewriter technology toward expanded applications and improved print quality. Interestingly, the invention of carbon paper actually predates the first practical writing machines. Around the turn of the nineteenth century, a form of carbon paper was produced in England using lard and lampblack. About twenty years later, an American, Cyrus Dakin, produced the first carbon sheet in the United States using a combination of ink and naphtha [6]. The first practical use of moving ink ribbon is credited to Giuseppe Ravizza in his 1867 writing machine model [1].

• *Fabric ribbons*
The early typewriter ribbon technology was almost entirely based on fabric ribbons. The earliest fabric ribbons were cotton and, because of the fiber absorbency, had fairly good ink capacity. Lint, however, was a problem and the randomness of filament size resulted in uneven print quality. Silk fabric provided smaller, more even filaments which gave good quality; the cost was high, however, and ink capacity was limited. Breakthroughs in the industry were then provided by synthetic fabrics such as nylon. Nylon filaments were small and uniform and when combined with a tight weave, provided a high-print-quality ribbon.

Technological change also impacted fabric ribbon inks as natural oils were replaced by synthetics, thus resulting in better viscosity control and reduced temperature sensitivity. Desire to improve print quality led IBM into ribbon development and manufacture in the mid-1950s. Prior to that time, all typewriter supplies had been provided by outside suppliers. Since that time, innovative developments have made supply products a significant part of IBM's typewriter business.

• *Film ribbons*
The first IBM supply innovation was in the area of film (total release) ribbons. Film ribbons had their origins in carbon paper technology. The degree to which carbon paper could be reused depended on the thickness of the ink coating, the adhesion of the ink to the paper backing relative to the cohesive strength of the ink, and the physical strength of the paper. Total-release ribbons, formulated to make only one pass through the typewriter, gave the secretary an opportunity to maintain consistent high-quality printing. Printing was darker because the ribbon could be loaded with pigments and the absence of a fabric weave resulted in characters with sharp edges.

IBM's first total-release ribbon used a paper substrate, but because it tore easily and did not conform well to the typeface, attention turned to plastic films. Polyester and polyethylene films were physically strong and could be extruded to a thickness of 25 microns and less. Polyethylene, however, conformed better to the character and was chosen as the substrate for the IBM 5121 Ribbon, introduced in 1960 for the IBM Model C typewriter. In 1964, this same ribbon material was introduced for the SELECTRIC Typewriter, which had previously pioneered a new concept in ribbon handling—a cartridge containing two spools mounted on the print-element carrier.

• *Solvent-coated ribbons*
Further ribbon innovations were to follow. Solvent-coated ink using a polyethylene substrate overcame the material limitations of previously used hot melt coatings. A new level of print quality was achieved when these solvent-coated inks proved they could provide better coverage for larger characters and maintain sharp impressions for small, intricate character shapes.

Solvent coating technology was also used to manufacture a third kind of ribbon, the IBM Tech III Ribbon, introduced in support of the SELECTRIC II Typewriter in 1971. Film ribbons provided superior print quality but ribbon changes were required more frequently than with fabric ribbons. Tech III Ribbons provided fabric ribbon life (580 000 characters), even though they were single-pass ribbons producing print quality very much like hot-melt film ribbon. Long life was achieved in this single-pass ribbon by using three separate "tracks" and allowing partial overstrike of the area used by previous characters. The ink, loaded with pigment to obtain character blackness, and the ink-carrying matrix, which replaced the fabric, were solvent-cast together from the same coating mixture. The product was truly a technological breakthrough in materials and processing techniques.

The Tech III Ribbon could possibly have become the standard of the industry had it not been for another technological breakthrough introduced eighteen months later. The Correctable Film Ribbon, along with its companion the Lift-Off Tape, established a new precedent wherein the supply product was the dominant feature of a new typewriter product, the Correcting SELECTRIC Typewriter.

• *Type elements*
Supplies innovations in support of typewriters have not been limited to ribbons. As mentioned, a key benefit of

the SELECTRIC Typewriter was the ability to easily and quickly change the print element. An almost overwhelming technical problem involved the manufacture of the element itself. Near-perfect placement of each character on the print element was required to ensure printing on paper within ±0.002 inch. Further, the print element had to be wear-resistant and stable under all conditions during the life of the machine. Two major technical developments were needed to make practical the manufacture of these interchangeable type elements: integrated plastic molding and a unique electroplating process.

While most plating is decorative, the type element was functionally plated using an electroplating process that enabled the metal skin to adhere to the plastic with tremendous tenacity. Even when the plastic contracted at a temperature of −75°C, the metal skin did not break off. Selection of the plastic involved extensive tests on no fewer than twenty-five types of plastics for impact strength, resistance to acids, shrinkage, and molding adaptability.

Innovation beyond the IBM SELECTRIC Typewriters

• *Improved print quality*
Striving for the best quality possible led to several improvements of the SELECTRIC Typewriter. One of the first was establishing better methods of print impression control.

In the original SELECTRIC Typewriter, all characters were printed at the same typehead velocity. A striker (on the print rocker) and an anvil (extending the length of carrier travel) were required to prevent small-area characters from penetrating excessively into the paper. Adjustment of the striker and anvil provided a measure of impression control; however, the adjustment was critical and could be made only by a customer engineer. Effort went into devising a more flexible, less critical means to control print impression and, in turn, quality. This consisted of a second, low-velocity print cam placed adjacent to the original print cam and selected when needed to limit penetration of small-area characters.

Operator impression control was provided by an adjustable lever that changed the multiplication ratio between the print cam(s) and the print rocker. These two design changes provided greater control over print impression and more uniform print quality.

• *Print quality plus—the IBM SELECTRIC Composer*
Typebar typewriters with proportional spacing had never achieved the print quality needed to compete favorably with "hot-type" composition. Previous shortcomings,

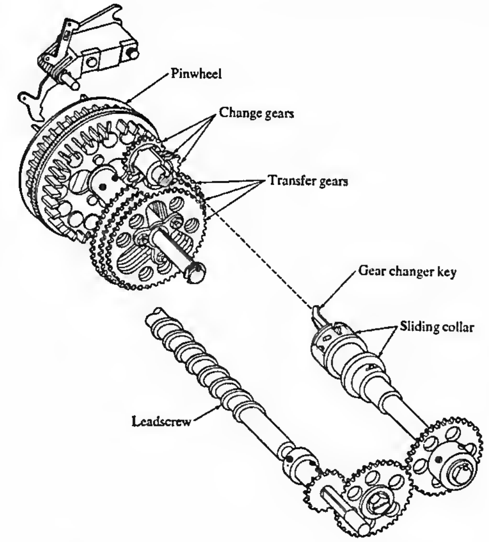

Figure 8 Simplified illustration of leadscrew, variable gear train, and pinwheel.

IBM believed, could be overcome with a machine based on single-element principles. This belief culminated in the announcement of the IBM SELECTRIC Composer, which amazed professional printers with its superior impact print quality.

The IBM SELECTRIC Composer was a significant challenge to mechanical typewriter technology because of the desire to emulate the print quality achieved in the best hot-type-composed publications. To meet these standards, the machine had to provide a wide variety of character widths, a selection of type sizes, a means to provide lines of equal length or right margin justification, and a method of impression control to provide uniform character coverage.

Because providing for an unlimited variety of type widths was impractical, a compromise was established at seven different, selectable widths. Thus, all fonts were designed to fit a proportional system that provided escapement values of three through nine units with three pitch sizes of 1/72, 1/84, and 1/96 inch. To provide this considerable flexibility, a leadscrew was chosen to drive and position the print element carrier (Fig. 8). Leadscrew rotation was under control of a pinwheel whose pins were set by a clamp ultimately controlled by vanes in the

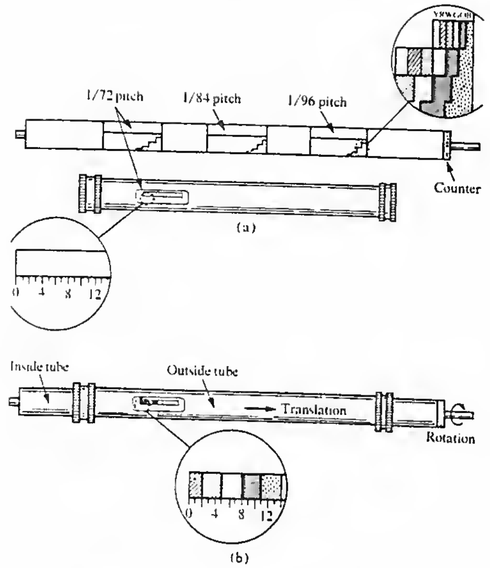

Figure 9 Indicating mechanism as used in Composer.

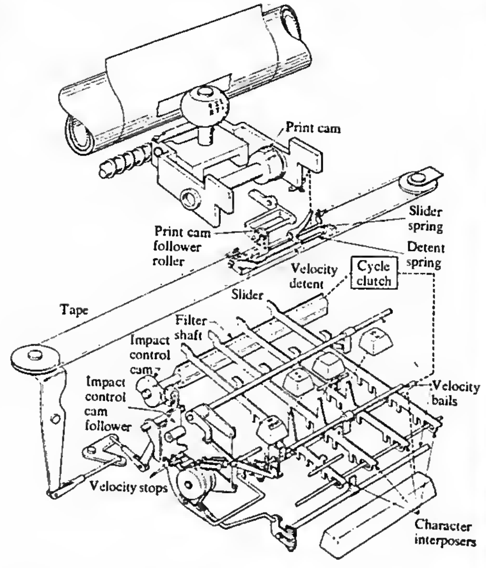

Figure 10 Impact selection system.

keyboard. The increment of pinwheel rotation was proportional to the number of units assigned to the character to be printed and was determined by the distance between set pins. A variable gear train was placed between the pinwheel and leadscrew to select carrier linear displacement of 1/72, 1/84, or 1/96 inch per unit of pinwheel rotation. In the final analysis, the escapement system was a mechanical calculator with means to both add and multiply [7].

A further requirement of the IBM SELECTRIC Composer—to type lines of equal length—was met by using a pair of concentric tubes. Figure 9(a) shows the indicating tubes separately. The inside tube (top) rotated to indicate the width (in escapement units) of the widest spaces needed to justify a line. The scale of the other, outside tube indicated how many of the spaces in the line needed to be expanded to that width. The outer tube did not rotate, but moved laterally to position the scale over the correct width indicator for the escapement pitch being used. Figure 9(b) shows the assembled indicating mechanism. The color next to zero represented the width of the expanded spaces, and the number beneath the first change in color identified the number of such spaces needed to justify the line. A mechanical magnification of 3:1 was necessary to allow the operator to read a scale graduated in units representing as little as 1/96 inch.

To justify a line of type between two selected margins, an operator would type the line twice—once to determine the amount of excess space between the last character in the line and the right-hand margin, and a second time to distribute that excess to the interword spaces along the line using a variable space bar. Following the first typing of the line, the variable space bar was set by the operator using selection dials that connected to a sliding code mechanism in the keyboard. Values to be set into the dials (represented by a color and a number) were established by visual indications as described above. This low-cost combination of mechanisms could justify any line of type, containing up to twenty spaces, that was nine to seventy-seven picas in length [8].

Impression control in the SELECTRIC Composer required a greater range of selection than was provided in the SELECTRIC Typewriter. Face areas of the type fonts designed for the Composer covered a range about five times greater than SELECTRIC Typewriter type styles. To cover this range, three automatic impact levels were chosen and characters were grouped into categories requiring low, medium, or high impact velocity. A set of four print cams (including one for non-print operation) shared a common cam follower. The cam follower was positioned by a steel tape and was stopped by latches at the appropriate cam. The latches were controlled by

velocity vanes in the keyboard (Fig. 10). Additional velocity control was afforded by the five-level manual impression control lever ("stick-shift") for the particular type font being used [9].

Achieving high print quality in the SELECTRIC Composer depended ultimately on a combination of the machine and a new supply product—a solvent-coated ribbon. Composer applications dictated its characteristics: easy release for large characters, sharp clear images for fine typestyles, and no ribbon ink dirt on the paper. The combination of machine and supply development set a level of impact printing quality that surpassed all existing devices. It was, however, the last typewriter to accomplish intricate functions mechanically.

- *IBM Correcting SELECTRIC Typewriter*

A typewriter innovation without precedent was the introduction of the IBM Correcting SELECTRIC Typewriter in 1973. The difficulty and inconvenience of correcting typing errors had been a problem ever since the first writing machines were invented. Manual methods of erasing and covering up errors provided the sole means of correction until typewriters with correctable magnetic recording media were introduced in the mid-1960s. Of course, these devices, which provided a form of automatic correction, were far more expensive than an ordinary typewriter. While working on a project to provide low-cost, memory-based error correction in a typewriter, a basic question was asked: Since the paper itself was a form of memory, why not correct errors directly from the keyboard using some form of correcting tape? Some rudimentary experiments were performed using a polyethylene ribbon which had been formulated about three years earlier with a special ink that could be lifted from the paper with pressure-sensitive adhesive. These experiments demonstrated crudely the feasibility of removing ink from ordinary and correctable bond paper; however, it was quickly realized that further formulation work was needed to improve the lift-off capability and print quality of the ribbon. Development efforts were soon to yield the IBM Correctable Film Ribbon.

Requirements for removable ink centered on its cohesive strength. It had to be cohesive enough to prevent penetration into the paper, yet not so cohesive that transfer from the ribbon substrate would be hampered, resulting in poor character coverage. An entirely new ink was developed based on a synthetic polymer that could be modified with additives to obtain the desired cohesive properties.

Coupled with the correctable ribbon was the need for a pressure-sensitive adhesive ribbon that could be activated when an error was to be removed. This adhesive ribbon had to adhere well to the ink, be of appropriate thickness to ensure contact with all edges of the printed character, and be strong enough to resist breaking when tension was applied. The materials for such a ribbon were identified through an extensive screening program. To handle applications where the lift-off system was inappropriate, a cover-up correction system was devised. This system used the Tech III Ribbon for imaging and a specially formulated cover-up tape.

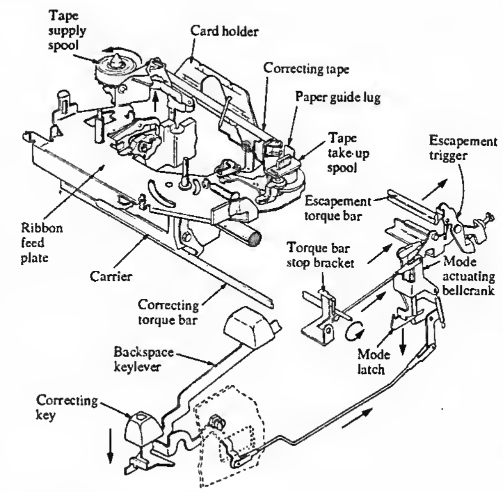

Figure 11 Correcting mechanism.

In the IBM Correcting SELECTRIC Typewriter, a number of design problems had to be solved. A means had to be provided to handle and feed the additional ribbons (either lift-off or cover-up). The grip of the adhesive ribbon on machine parts presented a problem which was solved by coating the cardholder and lift guides with polytetrafluoroethylene (PTFE). A ribbon-biasing mechanism was designed that would recognize whether the lift-off or the cover-up ribbon was in use and apply a much higher tension to the lift-off ribbon. After alternatives were considered, a semi-automatic mode of correction was designed. The character in error was restruck by the operator after depressing the "correcting" key that caused a backspace to occur and the correction ribbon to move into place (Fig. 11). In the view of the authors, this mechanism and its related supply items were as important to the SELECTRIC Typewriter technology as the shift key or visible writing line was to the typebar machines of Christopher Sholes' day.

• *Input and output*
Speed, character encoding, and cyclical operation eminently qualified the SELECTRIC Typewriter for automatic operation when it was used in conjunction with a computer or communications equipment. Similarly, the SELECTRIC Typewriter with input/output (I/O) capabilities coupled to magnetic media [*e.g.*, the Magnetic Tape SELECTRIC Typewriter (MT/ST) and the Mag Card SELECTRIC Typewriter] established the basis for today's burgeoning word processing industry. The development and further evolution of these ground-breaking products are described in this issue of the *IBM Journal of Research and Development* [10].

Development of the SELECTRIC I/O Typewriter virtually paralleled the design of the base machine. Developmental models were operational on experimental word processing and data processing systems when the SELECTRIC Typewriter was announced.

Approximately eleven months later the input/output version was announced. It was used initially as a computer system console typewriter, an agent terminal for airline reservation systems, and an automatic typewriter in the MT/ST. Many other manufacturers adapted it to their own word processing and data processing systems, and by the end of the decade the SELECTRIC I/O Typewriter was in widespread use throughout the industry.

The SELECTRIC Typewriter was well qualified for its input/output role. The seven-bit character selection code (six bits for rotate and tilt control and one for shift control) was a significant improvement over previous typebar I/O typewriters, which required a unique electrical signal for each character selected. Input operation was effected by adding seven sets of contacts for character selection plus a few additional contacts for function selection (carrier return, tab, backspace, and paper index). Similarly, output operation was facilitated by adding seven magnets for character selection plus a few additional magnets for the operational functions. Another significant advantage was the SELECTRIC I/O Typewriter speed of fifteen characters per second. This was fifty percent faster than other available output typewriters at that time.

Over the years, a number of changes to the SELECTRIC I/O Typewriter have been made. Modified versions have been introduced in a number of IBM word processing products such as the Mag Card Executive, Mag Card II, Memory Typewriter, and Electronic SELECTRIC Composer. The essential change in these versions was to make the connection between keyboard and printer electrical rather than mechanical. Thus, to operate the printer, the keyboard sent signals to electronic logic, which in turn sent signals to the printer magnets. The new design was more compact, permitted increased function, provided convenient control of that function through additional keyboard keys, and afforded a fully interlocked keyboard for all character and function keys.

Perhaps even more importantly, it provided the flexibility which, coupled with new large-scale integrated memory and logic, made possible the latest typewriter innovation: the electronic typewriter.

• *Electronic typewriters*
The revolutionary advances in microelectronics made possible the birth of the electronic typewriter. Functions previously beyond the ability of a typewriter to perform because of physical or cost limitations became possible. Thus, the initial innovative impact of electronic typewriters was in their dramatic price/performance improvements. Keyed text could be stored, altered, and printed at a fraction of the price of early word processing machines.

The introduction of the IBM Electronic Typewriter Models 50, 60, and 75 in 1978 and 1979 represented IBM's latest step in typewriter technology. At the heart of these new machines was a microcomputer with associated memory (RAM and ROM) and control circuits employing in excess of 170 000 transistors. The microcomputer's job was to interpret input signals from the keyboard and to actuate the appropriate electromagnets to cause printing and escapement of the carrier. Within the print module, which was not mechanically connected to the keyboard, the type element was tilted and rotated by cams that had pins and slides which were selected by solenoids energized by signals received from the microprocessor. Functions provided by the microprocessor in addition to print control and text storage included automatic carrier return, storage of up to fifteen keystrokes during carrier return, automatic error correction, column layout plus number alignment for statistical work, and automatic indenting and centering.

It appears that the full power of microprocessors has yet to be tapped. Application functions need only be defined to be implemented at a fraction of the cost previously possible. Diagnostic aids for operator and customer engineer can be designed to improve availability and serviceability. Certainly, the power and speed exist to control faster and quieter printers. Further, the potential exists to instruct and guide the typist in performing complex operations. In terms of storage capacities, large-scale integrated memories have broken the bounds of how much information can be stored within the covers of a typewriter. The Model 75 was announced with up to 15 500 bytes of memory, 5500 bytes more than the memory of the IBM 702 (introduced in 1953) and more memory than in some versions of the IBM System/360 Model 30 (introduced in 1964)! As uses are found for them, it seems safe to assume that much larger memories will be developed.

It would appear that with the current state of the art of I/O typewriters, and the seemingly unlimited potential of microelectronics, the future of typewriter innovation is extremely bright. It might even be fair to speculate whether in twenty-five more years we shall be willing to call the descendants of today's devices "typewriters."

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